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Control of Volatile Organic Emissions from Existing Stationary Sources. Volume V Surface Coating of Large Appliances

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(OAQPS No. 1.2-088)

GUIDELINE SERIES

CONTROL OF VOLATILE ORGANIC EMISSIONS FROM EXISTING STATIONARY SOURCES VOLUME V: SURFACE COATING OF LARGE APPLIANCES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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16. ABSTRACT

This document provides the necessary guidance for development of regulations to limit emissions of volatile organic compounds (VOC) from the coating operations of the large appliance industry. This guidance includes an emission limit which represents Reasonably Available Control Technology (RACT) for the large appliance industry, describes the industry, show the methods by which VOC emissions can be reduced in this industry and describes the monitoring and enforcement aspects.

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Emissions Standards and Engineering Division
Chemical and Petroleum Branch

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OAQPS GUIDELINE SERIES

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PREFACE

This document is one of a series designed to inform Regional, State and local air pollution control agencies of techniques available for reducing emissions of volatile organic compounds (VOC) from existing stationary sources. It deals with the surface coating of large appliances. For the purpose of this document, "large appliances" include doors, cases, lids, panels and interior support parts of residential and commercial washers, dryers, ranges, refrigerators, freezers, water heaters, dish washers, trash compactors, air conditioners and other similar products. The report describes the industry, identifies the sources and the types of VOC emissions, and the available methods and costs for minimizing these emissions. It also discusses techniques for monitoring the VOC content of surface coatings for purposes of determining compliance with anticipated regulations. More detailed discussions on coatings low in organic solvent and add-on control technologies are found in "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume I:Control Methods for Surface Coating Operations."[1] ASTM test methods for monitoring the solvent content of coatings are summarized in a previous report titled "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coil, Paper, Fabric, Automobiles and Light Duty Trucks,"[2]

The table below provides emission limitations that represent the presumptive norm that can be achieved through the application of reasonably available control technology (RACT). Reasonable available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably

[1] EPA-450/2-76-028, November 1976, (OAQPS No. 1.2-067)
[2] EPA-450/2-77-008, May 1977, (OAQPS No. 1.2-073)

available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical source categories. It must be cautioned that the limits reported in this Preface are based on capabilities and problems which are general to the industry, but may not be applicable to every plant.

Affected Facility	Recommended Limitation	
	kg of organic solvent per liter of coating (minus water)	lbs of organic solvent per gal. of coating (minus water)
Prime, single or topcoat application area, flashoff area and oven	0.34	2.8

This emission limit is based on the use of low organic solvent coatings. It can be achieved with coatings which contain at least 62 volume percent solids or any water-borne equivalent. This would result in approximately an 80 percent reduction in VOC emissions over conventional organic-borne coatings which contain about 25 volume percent solids. An equivalent reduction can also be achieved by use of add-on control devices such as incinerators or carbon adsorbers. Even greater reductions, 90 percent and more, can be achieved by conversion to electrodeposited water-borne or powder coatings. Since the large appliance industry includes a wide variety of products, there is no single control technique that can be considered best for the entire industry. It is believed that most facilities will seek to meet future regulations through the use of coatings which are low in organic solvent rather than resort to add-on control techniques.

GLOSSARY

- Prime coat means the first film of coating applied in a two-coat operation.
- Topcoat means the final film of coating applied in a two-coat operation.
- Interior single coat refers to a single film of coating applied to internal parts of large appliances that are not normally visible to the user.
- Exterior single coat is the same as the topcoat but is applied directly to the metal substrate omitting the primer application.
- Faraday caging means a repelling force generated during electrostatic spraying of powders in corners and small enclosed areas of metal substrate.
- Blocking agent means an agent which is released from the polymer matrix during the curing process. It is normally an organic radical and splits from the monomer or oligmer at a predetermined temperature, thereby exposing reactive sites which then combine to form the polymer. Such reactions during the curing process may release additional volatile organic compounds into the atmosphere.
- Low organic solvent coating refers to coatings which contain less organic solvents than the conventional coatings used by industry. Low organic solvent coatings include water-borne, higher-solids, electrodeposition and powder coatings.

CONVERSION FACTORS FOR METRIC UNITS

Metric Unit	Metric Name	Equivalent English Unit
Kg	kilogram (10^3 grams)	2.2046 lb
liter	liter	0.0353 ft^3
dscm	dry standard cubic meter	35.31 dry standard $ft.^3$
scmm	standard cubic meter per min.	35.31 ft^3 /min.
Mg	megagram (10^6 grams)	2,204.6 lb
metric ton	metric ton (10^6 grams)	2,204.6 lb

In keeping with U.S. Environmental Protection Agency policy, metric units are used in this report. These units may be converted to common English units by using the above conversion factors.

Temperature in degrees Celsius (C°) can be converted to temperature in degrees Farenheit (°F) by the following formula:

$t°_f = 1.8\ (t°_c) + 32$

$t°_f$ = temperature in degrees Farenheit

$t°_c$ = temperature in degrees Celsius or degrees Centigrade

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1.0 SOURCES AND TYPES OF EMISSIONS

This chapter provides a general introduction to the large appliance industry, the methods by which conventional coatings are applied, and the volatile organic solvent (VOC) emissions which can be expected from these coatings.

1.1 GENERAL DISCUSSION

A large appliance plant typically manufactures one or two different types of appliances and contains only one or two lines. The lines may range from 1200 to 4000 meters (3/4 to 2 1/2 miles) in length and operate at speeds of 3 to 15 meters (10 to 50 feet) per minute.

Coatings are a critical constituent to a large appliance. It must protect the metal from corrosion by its resistance, moisture, heat, detergent and sometimes the outdoor elements. Coatings for each type of appliance have special requirements and contains unique properties because each will be exposed to somewhat different corrosive elements. The coatings must also be durable and excellent adhesion properties to avoid peeling or chipping which would then expose the metal to corrosive attack. Finally, the coatings that are applied on home appliances must have esthetic appeal.

1.2 PROCESSES AND EMISSION POINTS

The coatings typically applied on large appliances are epoxy, expoy-acrylic, acrylic or polyester enamels. Coatings containing alkyd resins have also been used in some cases. The single coat for interior parts

and primers are applied in one or two colors, and the single coats for exterior parts and topcoats in several colors. Sometimes two variants of the same color are used on the topcoat or exterior single coat to provide a shaded effect on the appliance. A black asphalt-type gilsonite coating is also applied on some large appliance parts to provide additional moisture resistance and to act as a sound deadener. Prime and interior single coat materials are applied at 25 to 36 volume percent solids, and topcoat and exterior single coats at 30 to 40 volume percent solids. Many coatings are purchased at higher solids contents but are thinned with solvents before application. Quick-drying lacquers are also applied on some large appliances to repair scratches and nicks that occur during assembly; they are applied sporadically at approximately 20 volume percent solids, and often amount to approximately one quart per shift.[1] Because of the small quantity used, these coatings are exempt from being required to meet any emission limits.

Coatings applied on large appliances may contain mixtures of 2 to 15 different solvents. The typical solvents used are esters, ketones, aliphatics, alcohols, aromatics, ethers and terpenes. The solvents used to carry the solids to the substrate are blended to control viscosity and evaporation rate as well as other properties to assure a continuous durable film and a lusterous appearance.

Each large appliance assembly line tends to be unique because of its age, the different types and styles of large appliances manufactured and the type of coating application equipment. Figure 1.1 portrays features common to many large appliance lines. The following comments summarize the steps in the process.

Cases, doors, lids, panels and interior parts for large appliances are stamped from sheet metal and hung on overhead conveyors. The parts are transported to the cleaning and pretreatment sections typically located on the ground floor of the plant. The parts are cleaned with an alkaline solution to remove grease, mill scale or dirt, rinsed, treated with zinc or iron phosphate, rinsed again, and treated with chromate if iron phosphate is used. The parts are then dried at 300-400°, typically in a gas fired oven and cooled before coating. The prime coat, if required, or interior single coat may be applied by dipping, flowcoating or by electrostatic spraying and varies in thickness from 0.5-1.0 mils. Sometimes the cured flowcoat is followed by a manual spray operation for touchup. Dip coating is typically used for small parts while flow or spray coating are used for larger parts.

On some lines the parts enter a prime preparation booth to check the pretreatment. Here the parts can be sanded and tack-ragged (wiped) to provide an even finish. Such treatment is usually necessary only for exterior parts such as doors, lids, cases and panels, where a smooth finish is important.

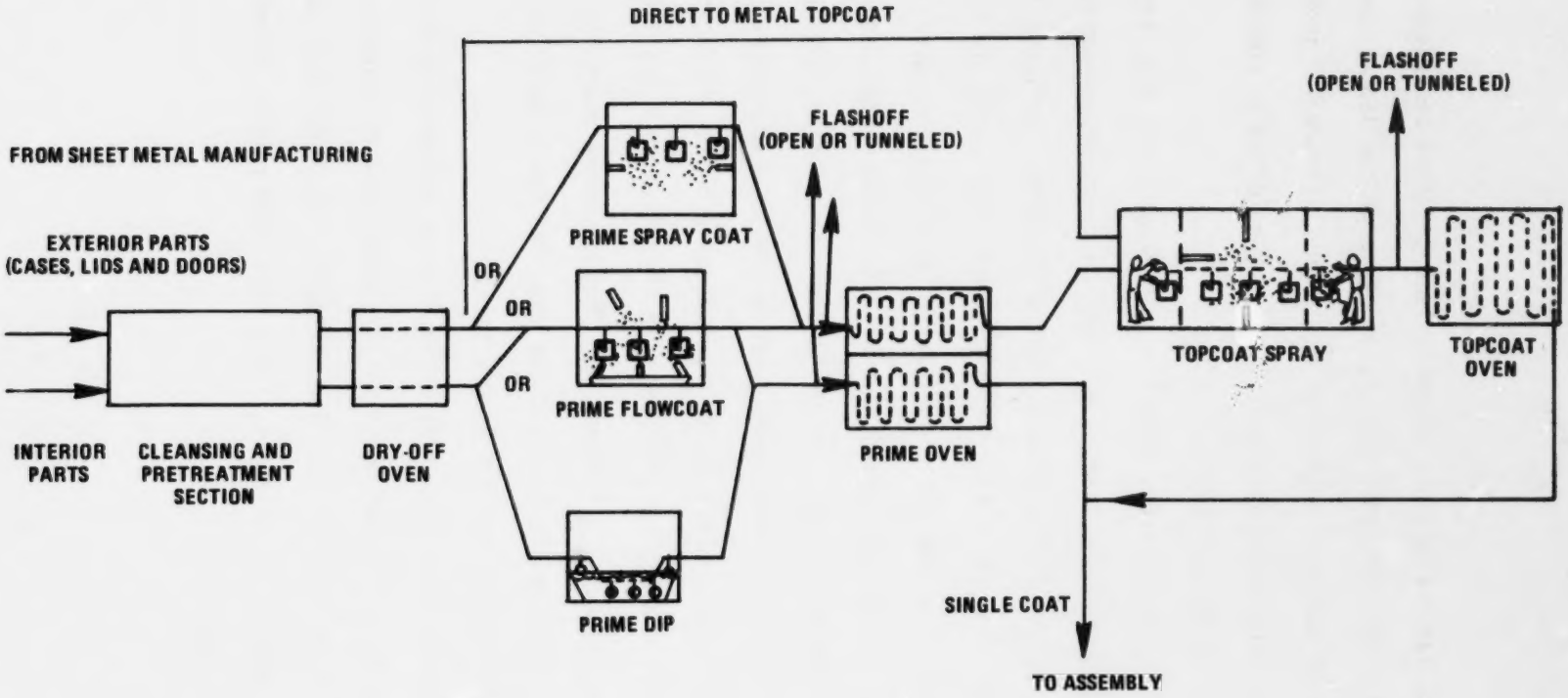

Figure 1-1 Diagram of a large appliance coating line.

If the prime or single coat is dip coated, the coating is contained in a continuously agitated tank to prevent settling. As the parts move on the conveyor, they are immersed into the coating, withdrawn and the excess coating is allowed to drain back into the tank. Viscosity is critical in dip coating. If the viscosity is too low, the coating film will be too thin, if it is too high, the coating film will be too thick, resulting in high coating usage and drip marks. The dip coating tank and drain board may be completely enclosed and vented by roof fans, or may have a ventilation system adjoining the tank and drain board. Ventilation rates range from 30 to 230 scmm (1000-8000 scfm) at VOC concentrations of 1 to 3 percent of the lower explosive limit (LEL).

In the flowcoating process, the parts are moved by a conveyor through an enclosed booth. A series of stationary or oscillating nozzles, located at various angles, shoot out streams of coating which flow over the part. Excess coating,which drains into a sink on the bottom of the booth, is filtered and recycled. As in dip coating, the viscosity of the coating is critical. Coated parts may enter a flashoff tunnel to allow time for the coating to flow out properly. After being baked in the oven, the flow-coated parts may be manually touched-up in a spray booth with conventional spray equipment. The exhaust from the flowcoater and tunnel may range from 28 to 1841 scmm (1000-65,000 scfm) with VOC concentrations from 1-5 percent LEL. The exhaust from the manual touch-up spray booth may range from 425 to 850 scmm (15,000-30,000 scfm) depending on booth and size of the openings. VOC concentrations will vary from 0 to 1 percent LEL because these touch-up coatings are applied sporadically as needed. Total emissions are usually too low, less than a liter each day, to warrant control.

Some primers are applied by automatic electrostatic spraying with disc, bell or other types of spray equipment. As the paint particles exit in a spray, they are negatively charged, and are attracted to the grounded appliance part, coating it. This method is about 70-80 percent efficient in transfer efficiency and provides some reduction in VOC emissions over conventional spray equipment. (Conventional spray equipment is about 40-70 percent efficient.) Primer touch-up is sprayed manually.

Spray coating is performed in a spray booth to contain any overspray, to prevent plant or outside dirt coming in contact with the paint, and to control the temperature and humidity at the point of application. Down-draft and side-draft spray booths areused in the large appliance industry. Each may be 15.24m (50 feet) long. The spray booths are usually equipped with dry filters or a water wash to trap any overspray. The make-up air for a spray booth is often kept at about 24°C (75°F) and 35 to 50 percent relative humidity during the winter months for proper coating application. Dryness in the spray booths will cause arcing due to electrostatic spray equipment. During the other months, however, spray booth controls are not necessary and only different thinners are needed in the coatings to compensate for the different weather conditions. Air flow from the spray booths range from 2200 to 3500 scmm (80,000-125,000 scfm) for automatic and 550 to 1700 scmm (20,000-60,000 scfm) for manual spray applications. The minimum air velocities in the manual spray booths are prescribed by OSHA for the safety of workers and are a function of the cross sectional area of the spray booth.

The prime and single coated large appliance parts often go through about a seven minute flash-off period to allow the solvents to rise slowly in the coating film to avoid popping of the film as the coating is baked. The flash-off area may be contained in a "vapor release" or flash off tunnel. The exhaust from the tunnel is about 60 to 230 scmm (2000-8000 scfm) with a VOC concentration of 1 to 5 percent LEL.

Typically, coated parts are baked for about 20 minutes at 180° to 230°C (350-450°F) in a multi-pass oven. An air velocity of 15 to 45 mpm (50 to 150 fpm) is often required through these openings to prevent the effluent from spilling into the working area. Since the entry and exit openings of the ovens are sized to accommodate the largest parts to be coated, this often results in exhaust rates higher than what would be required to merely maintain the oven at 25 percent LEL, as recommended by many insurance companies. (Some insurance companies allow operation at 50 percent LEL with proper monitoring equipment.) Air curtains at oven openings permit reduction of the air velocity to about 15 mpm (5p fpm). Other factors which affect the exhaust rate are the humidity, air flow requirements for proper curing, and condensation/corrosion problems of interior oven surfaces. Consideration of these factors have resulted in oven exhaust rates from 280 to 1400 scmm (10,000-50,000 scfm) and VOC concentrations as low as 5 percent LEL or less.

Before the parts are topcoated, they are checked for smoothness, manually sanded if necessary, "tack-ragged", and retouched with a manual spray gun. Topcoat or exterior single coat (direct-to-metal topcoat) is usually applied by automated electrostatic discs, bell or other type of spray equipment at coating thickness of 1.0 to 1.5 mils. Such electrostatic spray equipment is usually about 70 to 85 percent efficiency in transfer efficiency.

The spinning disc oscillates vertically, coating the part as it moves around the disc. There may be as many as 8 discslocated in sequence. The bells or other spray equipment are located at various angles on each side and bottom of the spray booth, coating the parts as they move on an overhead conveyor. There may be as many as 50 sprayers for a single topcoat application. Topcoat is usually applied in many colors. Topcoat color changes are accomplished after automatically flushing the system with solvent and take only a few seconds. The flushing solvent can be returned to a solvent container for reuse or disposal, or be sprayed directly into the spray booth. Topcoated parts then move to a manual spray application for touching up and applying any highlighting tones.

Topcoat and exterior single coat are applied in side-draft or down-draft spray booths usually equipped with a water wash. The air is cleansed to remove any dust particles. The air during the winter months is typically maintained at temperatures of 20 to 30°C (70-85°) and 35-50 percent relative humidity to prevent arcing of electrostatic equipment. During the other months, the thinners are varied to compensate for the weather conditions. The automatic spray booth exhaust will vary from 2250 to 3500 scmm (80,000 to 125,000 scfm) at concentrations of 0.5 to 1 percent LEL, whereas exhaust from the manual spray booths (smaller in size) is prescribed by OSHA and may vary from 550 to 1700 scmm (20,000 to 60,000 scmm) at concentrations of 0.08 to 0.5 percent of the LEL. (OSHA regulations specify minimal allowable conditions.)

The topcoated part then undergoes a 10 minute flashoff period to allow the solvents to rise in the coating film. The flashoff area is typically enclosed, and the exhaust rate is about 60 to 230 scmm (2000 to 8000 scfm) with VOC concentrations of 1 to 5 percent LEL.

The topcoat is finally baked for 20 to 30 minutes at 140 to 180°C (270-350°F) in a multi-pass oven. The exhaust may range from 280 to 1400 scmm (10,000-50,000 scfm) depending on the size of the opening through which the parts enter. VOC concentrations range from 5 to 10 percent LEL.

The inside of many exterior large appliance parts are sprayed with gilsonite for additonal moisture resistance and for sound deadening. This coating is typically sprayed at about 25-30 volume percent solids.

In summary, organic vapor emissions from the coating of large appliances are emitted from application areas, flashoff tunnels, and ovens. Estimates of the relative amounts of VOC emissions from these sources are listed in Table 1.1.

Figure 1.2 displays the relationshop between VOC emissions and flowrate with isopleths of organic concentration (LEL). Note that for a given emission rate, the exhaust flowrate at 1 percent LEL concentration is 10 times that at 10 percent LEL. The flowrate and resulting concentrations are a function of many factors; open or enclosed spray booths, dip or flowcoater, flashoff area or an oven. Unfortunately, flowrates are often designed for the most difficult parts to be coated by the line and may be excessive for the typical piece.

Table 1.1 PERCENT DISTRIBUTION OF VOC EMISSIONS FROM LARGE APPLIANCE COATING LINES[a]

Application Method	Application and Flashoff	Oven
Dip	50	50
Flow coat	60	40
Spray	80	20

[a]The base case coating is applied at 25 volume percent solids, 75 percent organic solvent organic solvent which is equivalent to a VOC emission factor of 0.66 kg of organic solvent emitted per liter of coating (5.5 lbs/gal) minus water.

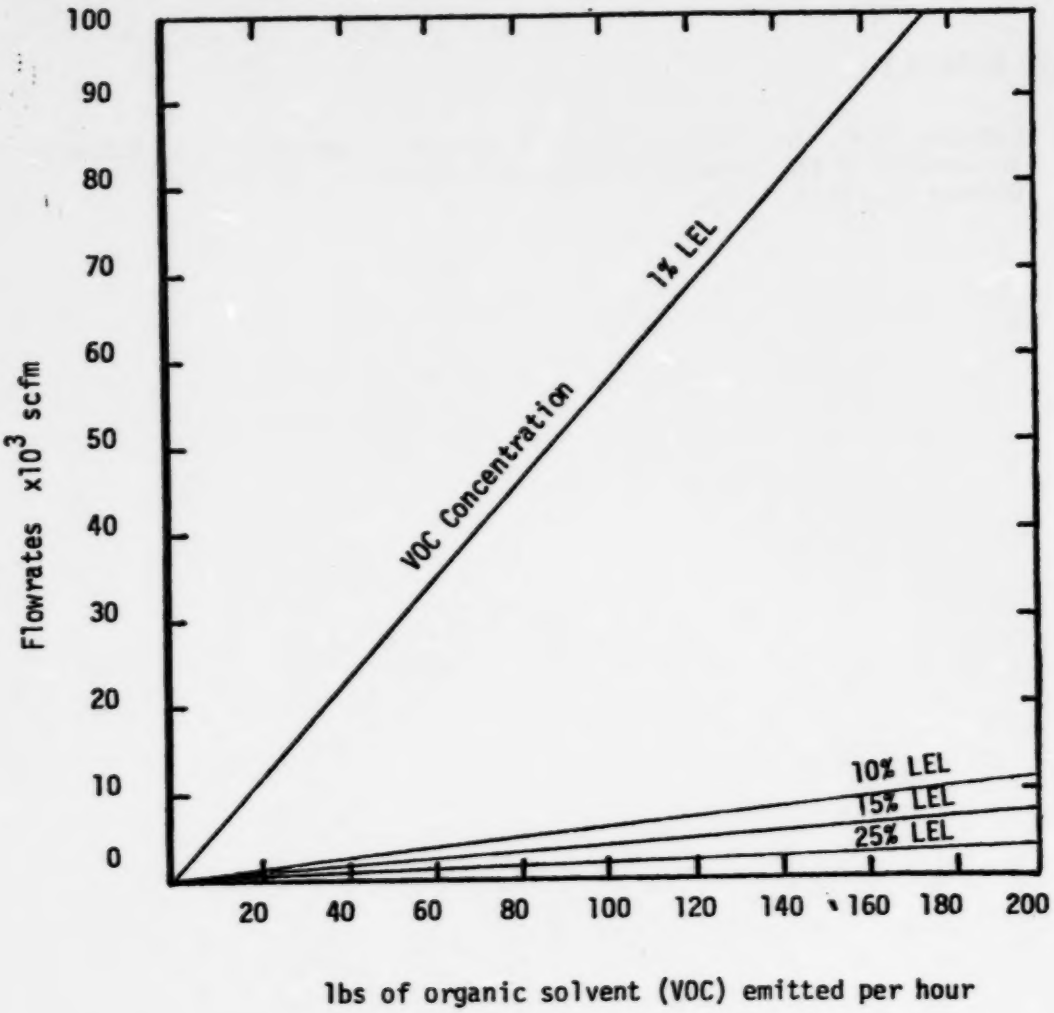

Figure 1.2 Relationship between VOC emissions, exhaust flowrates and VOC concentrations.

1.3 REFERENCE

1. Connors, E.W., Jr., General Electric Company. Letter to V.N. Gallagher in comment of the large appliance draft document. Letter dated October 10, 1977.

2.0 APPLICABLE SYSTEMS OF EMISSION REDUCTION

This chapter discusses coatings low in organic solvents and add-on equipment for the control of VOC from conventional coating applications used in the large appliance industry. It also discusses other methods of applying coatings (powder and electrodeposition) which result in low VOC emissions.

Table 2.1 SUMMARY OF APPLICABLE CONTROL TECHNOLOGY FOR LARGE APPLIANCE DOORS, LIDS, PANELS, CASES, AND INTERIOR PARTS

Control Technology	Application	Percent Reduction In Organic Emissions
Water-borne (Electrodeposition)	Prime or interior single coat	90-95[a]
Water-borne (Spray, Dip, or Flowcoat)	All applications	70-90[a]
Powder	Top, exterior, or interior single coat	95-99[a]
Higher solids (Spray)	Top or exterior single coat and sound deadener	60-80[a]
Carbon adsorption	Prime, single or topcoat application, and flashoff areas	90[b]
Incineration	Ovens	90[b]

[a]The base case against which these percent reductions were calculated is a high organic solvent coating which contains 25 volume percent solids and 75 percent organic solvent. The transfer efficiencies for liquid coatings were calculated to be 80 percent, for powders about 93 percent, and for electrodeposition about 99 percent.

[b]This percent reduction in VOC emissions is only across the control device, and does not take into account the capture efficiency.

2.1 ELECTRODEPOSITION

Many large appliance manufacturers have changed to the electrodeposition technique for applying the prime coat on large appliance exterior parts (doors, panels, lids and case) and for applying a single coat on large appliance interior parts.[1,2,3,4] The main reason for switching was increased corrosion protection and increased detergent resistance, especially in clothes washers and dryers. The electrodeposition coatings may be applied at 0.5 to 1.0 mils thickness; film thickness is adjusted by voltage and immersion time.

The dry-off oven may be omitted after cleansing of the large appliance parts if iron phosphate pretreatment is used. An additional rinse of deionized water is necessary. After rinsing the parts are grounded and immersed into a coating bath containing about 8 to 15 volume percent solids and 2 to 4 volume percent organic solvent, the balance being water. A direct current is applied in the bath, causing the solids to become attached to the grounded metal part. The coating may be applied either by anodic or cathodic electrodeposition. As the parts emerge from the bath, the applied coating consists of approximately 90 volume percent solids and 2 to 4 volume percent organic solvent. This provides about 90-95 percent reduction in organic e emissions over conventional processes. The parts are then rinsed in several stages to eliminate excess paint particles. The coating is then baked in an oven at about 200°C (400°F). VOC emissions from an EDP line are emitted from the coating bath, the rinsing stages (if the ultrafiltrate is directed to the rinse instead of being purged into the sewer), and the oven. In converting to electrodeposition, the flashoff tunnel can be eliminated, and the oven exhaust may be reduced due to the substantial decrease in organic solvent. This results in additional energy savings.

For further technical details on the use of electrodeposition coating technology, see Volume I, Section 3.3.1.[5]

2.2 WATER-BORNE - SPRAY, DIP, OR FLOWCOAT

Water-borne coatings have similar application characteristics to organic solvent-borne coatings, thus conversion to water-borne coatings does not often require installation of new application equipment. Organic solvent-borne systems such as flow or dip coaters have been successfully converted to water-borne coatings.[6,7] However, some alterations usually are necessary to protect equipment from corrosion, provide a longer flashoff area, or to control the humidity in application and flashoff areas. Water-borne coatings may be sprayed electrostatically providing the entire system is electrically isolated Some small electrostatic lines have been converted to water-borne coatings. Larger lines, however, may have difficulty converting to water-borne coatings, because of electrostatic spray equipment used or because the storage areas from where the coatings are pumped may be thousands of feet away from the application areas, making electrical isolation difficult and sometimes financially impractical.[8,9,10,11]

Since water has a single boiling point, and a slower evaporation rate than most organic solvents, it is often necessary to include some organic solvents to temper the evaporation rate, provide the coating with necessary properties, and to provide film coalescence. A reduction of 70-90 percent in VOC emissions may be achieved by switching to water-borne coatings. The actual reduction will depend on the composition of the water-borne coating replacement. Further technical details on the use of water-borne coatings may be found in Volume I, Section 3.3.1 and 3.3.5.[12]

2.3 POWDER

Powder coatings are presently being applied (often as a replacement for porcelain) for topcoats on some range parts, and as interior single coats for refrigerator liners and some washer and dryer parts.[13,14,15] These would usually be applied by electrostatic spraying because dipping would produce excessive film thickness. About 2-4 mils film thickness may be achieved by spraying. After application of the coating, the powder particles are completely melted in the oven to form a continuous, solid film. Although powders appear to be essentially all solids, they do contain entrapped organics which are released during the curing process, often as a result of cross-linking reactions.[16]

Applying powder by electrostatic spray uses almost the same technique as do solvent-borne coatings, and may be done either manually or automatically. As the particles emerge from the spray gun, they become charged, and are subsequently attracted to the grounded metal part. Powder coatings do not coat well within small recesses. This problem may be reduced or eliminated by preheating the parts. However, this will result in thicker films of coating.

Powder overspray can be reclaimed providing up to a 98 percent coating utilization. Color changes, if the powder is recovered, require that the booth and recovery units be cleaned to avoid color contamination. If the overspray powders are not recovered, color change periods may be shortened. However, this reduces the coating utilization efficiency to about 60 percent.

To shorten the time required for a color changeover, some facilities have several recovery units available that may easily be attached to the spray booths. Others have installed several mobile spray booths with associated recovery equipment.[17]

Powder coatings do not require flashoff tunnels, and are baked at temperatures of 180 to 230°C (300-450°F). Since the concentrations of VOC are almost insignificant compared to conventional coatings smaller ovens may be installed with attendant reductions in air flow. Further technical details on the application of powder coatings may be found in Volume I, Section 3.3.3 and 3.3.5.[18]

2.4 HIGHER SOLIDS (SPRAY)

The reduction in volatile organic emissions achievable by switching to a coating containing higher solids may range from 50 to 80 percent, depending on the original and replacement coatings. Medium-high solids coatings (45-50 volume percent solids) are being applied as topcoats on some refrigerators with prospects of even greater solids content as heated application equipment can be perfected.[19] Higher solid (50-60 volume percent) gilsonite coatings can also be applied for sound deadeners.

Higher solids coatings can be applied most efficiently by automated electrostatic spraying although manual and conventional spraying techniques can also be used. Some increase in energy may be required to increase the pressure of the spray gun, the temperature of the coating or power of the electrostatic spray equipment in order to pump and atomize these coatings due to their higher viscosities. Transfer efficiencies of higher solids coatings are often better than those of conventional coatings, particularly when sprayed electrostatically.[20]

As the solids content is increased, less organic solvent is evaporated for each dry mil of coating. This can allow a reduction on the amount of air through the spray booth required to keep the coating particles and volatile organics away from the coating personnel. This will result in an energy savings.[21] The lower solvent content also enables the air flow from the flashoff tunnel and oven to be reduced.

Further technical details on the use of high-solids coatings may be found in Volume I, Section 3.3.2.[22]

2.5 CARBON ADSORPTION

As discussed in Chapter 1, at least two thirds of the volatile compounds from large appliance coatings are emitted from the application and flashoff areas. The remainder is emitted from the ovens The use of carbon adsorption for the application and flashoff areas can reduce VOC emissions from those areas by 75-90 percent, depending on the capture efficiency into the control device.

Carbon adsorption is considered a viable control option for the application and flashoff areas although there are no known carbon adsorption systems in plants which manufacture large appliances. Adsorption is technically feasible for these applications in that no new inventions are required for its implementation.[23] Pilot studies, however, may be necessary before this control technology is installed.

The size of a carbon adsorption unit is dependent on the exhaust flow rate, VOC concentration, and the desorption period. The flowrates and concentrations will vary with each application because of the variety of large appliance parts coated. Flow rates may range from 30 scmm (1000 scfm)

for a small dip coater to 4500 scmm (160,000 scfm) for topcoat or exterior single coat spray booths, and from 150 to 280 scmm (5000 to 10,000 scfm) for a flashoff tunnel. Concentration of volatile organic compounds from a down-draft booth are about 0.25 to 1 percent of the LEL; from a flowcoater about 1 to 3 percent of the LEL, and from the flashoff tunnel about 1 to 5 percent of the LEL. If coatings are applied sporadically, the concentration of solvents in the exhaust will vary during any given time period from 0 to 1 percent LEL. The size of the carbon adsorber can be minimized (thus reducing capital and operating costs) by routing the discharge air from the areas where the coating is applied manually to those applied automatically. Particulate matter from overspray is often captured at about 95 percent efficiency by dry filters, or by water or oil wash curtains and should not coat the carbon bed.[24] Additional filtration may be necessary, however, if the residual particulate is significant enough to pose a threat to the adsorber bed.

Flashoff areas are often enclosed. However, on lines where they are not, they will have to be enclosed. The flow rates and concentrations of exhaust from the flashoff areas will largely depend on the configuration of the coating line. If the coating application areas are located on the first floor of the plant, for example, and the ovens are mounted on the roof, enclosure may be very difficult. In other cases, the application area may be located near the oven, and enclosing the flashoff area would be less difficult. In some situations, the negative pressure maintained in the oven will entrain the solvent laden flashoff air into the oven.

Further details on the use of carbon adsorption may be found in Volume I, Section 3.2.1.[25]

2.6 INCINERATORS

There are no serious technical problems associated with the use of either catalytic or non-catalytic incinerators on large applinace facilities. Incineration has been used to reduce VOC emissions from large appliance ovens.

Incinerators may be less costly and perhaps more efficienct than carbon adsorbers for reducing organic emissions from many large appliance baking ovens for several reasons: (1) the high temperature oven exhaust (150 to 230°C) would have to be cooled before entering a carbon bed. This would result in high energy usage; (2) although additional energy is required to being the oven exhaust near incineration temperature, this energy can be minimized by the use of primary heat exchangers; (3) the concentration of organic vapors is often higher in the oven exhaust providing some additional fuel for the incinerator; (4) particulate and condensible matter from volatilization and/or degradation of resin which often occurs in higher temperaturebaking ovens will not affect an incinerator. It could coat a carbon bed and render it inefficient even when a filter is used.

It will normally be desirable (but not always possible) to incorporate heat recovery systems (aside preheating of the oven exahust) to reduce fuel consumption to a minimum level. Incinerator exhaust heat may be recovered for use in many areas, for example, the cleansing and pretreatment sections, the ovens and for plant and spray booth heating during the winter months. Incineration for application and flashoff areas is also a viable control option if sufficient heat recovery can be used to keep fuel consumption at an acceptable level.

Otherwise, incineration of ambient temperature, low concentration gas streams is energy intensive.

Further technical details on the use of incineration may be found in Volume I, Section 3.2.2.[26]

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3.0 COST OF CONTROL OPTIONS

3.1 INTRODUCTION

3.1.1 Purpose

The purpose of this chapter is to present estimated costs for control of volatile organic compound (VOC) emissions from coating lines at existing major appliance plants.

3.1.2 Scope

Estimates of capital and annualized costs are presented for controlling solvent emissions from application areas and curing ovens in prime and topcoat electrostatic spray coating lines. Two categories of VOC control techniques considered applicable to a coating line using the conventional solvent-borne coating have been costed: process modifications and add-on control systems.

The process modifications involve converting of a solvent-borne prime or topcoat line to a coating system which emits lesser amounts of VOC. The coating lines and the modifications costed for them are:

1. Prime:
    (a) Electrodeposition (EDP)
    (b) Water-borne
2. Topcoat:
    (a) High-solids
    (b) Water-borne
    (c) Powder
3. Prime/Topcoat: Powder

(The coating processes are fully described in Chapter Two.)

Also, note that the control costs for prime coating lines are also applicable to single coat operations.

The add-on control systems costed are carbon adsorption and thermal incineration with primary heat recovery. Adsorption is for controlling VOC emissions from the topcoat spray booth and flash-off area, while incineration controls the topcoat curing oven.

Detailed control cost estimates are developed for a model medium-sized existing coating line, with annual production rates of 768,000, 1,536,000, and 2,304,000 units/year (clothes washer cabinets), representing one, two, and three-shift/day operation, respectively. Each unit requires 5.4 m^2 (58 ft^2) of coating in the prime application, and 2.7 m^2 (29 ft^2) in the topcoat application.

Cost-effectiveness ratios (i.e., incremental annualized cost per incremental weight of VOC controlled) have also been computed for each of the alternative control systems , at these model coating line production rates.

In general, these cost-effectiveness ratios only apply to the coating of clothes washer cabinets. However, because the costs of add-on control systems depend on parameters whose values are more or less independent of the type of appliance being coated (e.g., volumetric flowrate), their cost-effectiveness ratios could be applied to other products, such as refrigerators. On the other hand, the design and, in turn, the costs of coating equipment are more dependent on the appliance being coated. Despite this, the process modification cost-effectiveness values may (with caution) be extrapolated to other major appliances.

3.1.3 Use of Model Plants

The cost analyses provided in this chapter rely on the use of model coating lines, basically defined by a baseline annual production rate (768,000 units/year) and three operating factors (1,920, 3,840, and 5,760 hours/year).[1,2] No attempt has been made to provide detailed design characteristics of the coating line process equipment.

An EPA contractor has furnished most of the technical parameters upon which the control costs have been based.[1] Listed in Table 3-1, these parameters have been selected to reflect typical operating conditions at actual major appliance plants. However, most of the process modification costs have been furnished by industry members.[3 to 7] Costs for add-on control systems, however, have been primarily obtained from a compendium of air pollution control costs, with appropriate revisions.[8,9]

Although model plant control cost estimates may differ with actual costs incurred, they are the most convenient means for comparing the relative costs of the alternative control measures.

3.1.4 Bases for Capital Cost Estimates

Each capital cost represents the total investment necessary for purchase and installation of a control alternative (i.e., process modification or add-on system) in an existing plant--retrofit installations, in other words. Major and auxiliary equipment purchase and installation costs have been obtained from actual installations or vendors. Costs for research and development, production losses during installation, start-up, and

Table 3-1. TECHNICAL PARAMETERS USED IN DEVELOPING CONTROL COSTS[a]

I. Coating Line Baseline Production Rate:	768,000 units/yr.
II. Operating Factors:	1,920, 3,840, and 5,760 hours/yr.
III. Baseline VOC Emission Rates (Concentrations)	
1. Prime coat line:	
- Spray booth and application area	157, 314, and 471 Mg/yr. (1% LEL)
- Oven	39.2, 78.4, and 118 Mg/yr. (15% LEL)
2. Topcoat line:	
- Spray booth and application area	95.2, 190, and 286 Mg./yr. (1% LEL)
- Oven	23.8, 47.6, and 71.4 Mg/yr. (15% LEL)
IV. VOC Control Efficiencies:	
1. Add-on control systems	
- Thermal incineration	90%
- Carbon adsorption	90%
2. Process Modifications	
- Water-borne coating	80%
- High-solids coating	76%
- Powder coating	95%
- Electrodeposition coating	87%
V. Volumetric Flowrates (Temperatures)[b]	
1. Thermal incineration	43.9 m^3/min. (at 149°C)
2. Carbon adsorption	1,840 m^3/min. (at 21°C)

[a]References 1 and 2.

[b]These are the flowrates and temperatures at the add-on control system inlets.

other highly variable costs are not included in the estimates. All capital costs represent first quarter 1977 dollars.

In the case of a process modification, the capital cost simply represents the cost for modifying the existing solvent spray coating line, by removing the old equipment and installing the new. Depending on the modification, the cost may be small or large, relative to the existing coating line investment.

For add-on systems, however, the capital cost is that for installing the control equipment on an existing spray booth or oven. None of the coating equipment is modified, and, consequently, the capital cost is virtually independent of the existing solvent line configuration.

3.1.5 Bases for Annualized Cost Estimates

Annualized cost estimates for the control alternatives consist of: direct operating costs, solvent credits, and annualized capital charges.

Direct operating costs include expenditures for: labor and materials for operating the control equipment (except solvent); utilities, such as electric power and natural gas; disposal of liquid and/or solid wastes generated by the control alternative; and maintenance labor and supplies. With process modifications, these costs represent the difference or "increment" between the respective costs incurred by the new coating system and those for the existing solvent coating line. For the add-on controls, the costs are merely those for the operation and maintenance of the control equipment.

The solvent credit represents the difference between the solvent cost for the process modification and that for the baseline, solvent-borne

coating line. Because the process modification requires (and emits) less solvent than the baseline process, this value is always negative, i.e., a credit. This credit does not apply to add-on control systems, however. This is so because the solvent captured by carbon adsorbers cannot be reused, while incinerators oxidize the solvent to carbon dioxide, water, and other combustion products.

The annualized capital charges are subdivided into costs for depreciation and interest and costs for taxes, insurance, and administration. Depreciation and interest have been computed by a capital recovery factor whose value is based on the depreciable life of the control equipment and the annual interest rate. (A twelve-year life and ten percent interest rate have been assumed for each control alternative.) Four percent per year for taxes, insurance, and administrative charges is added to this recovery factor, and the sum is multiplied by the capital cost, yielding the annualized capital charges.

The total annualized cost is obtained by summing the direct operating cost and annualized capital charges and subtracting from this sum the solvent credit.

The annualized costs are for a one-year period beginning with the first quarter of 1977. Factors used to compute the annualized cost are listed in Table 3-2.

3.2 CONTROL OF SOLVENT EMISSIONS FROM LARGE APPLIANCE COATING OPERATIONS

3.2.1 Control Costs

Cost estimates for retrofitting new coating systems, carbon adsorption, and thermal incineration systems to the model solvent prime and topcoat

Table 3-2. COST FACTORS USED IN COMPUTING ANNUALIZED COSTS[a]

I. Direct Operating Costs	
1. Materials:	
- Solvent coating (prime):	$1.72/liter ($6.50/gal.)
- Solvent coating (top):	$2.13/liter ($8.05/gal)
- Solvent coating (solvent thinner):	$0.28/liter ($1.07/gal)
- Powder coating:	$3.85/Kg ($1.75/lb)
- Spray water-borne coating:	$2.11/liter ($8.00/gal)
- Electrodeposition water-borne coating:	$1.93/liter ($7.30/gal)
- High-solids coating:	$3.17/liter ($12.00/gal)
- Carbon	$2.20/Kg ($1.00/lb)
2. Utilities	
- Electricity	$0.025/kw-hr
- Natural gas	$1.90/thousand joules ($2.00/million Btu)
- Steam	$5.50/thousand Kg ($2.50/thousand lb)
- Boiler feed water	$0.13/thousand liters ($0.50/thousand gal)
3. Direct Labor	$10/man-hour
4. Maintenance Labor	
- Process modifications	$10/man-hour
- Add-on systems	0.02 x Capital Cost
5. Maintenance Materials	0.02 x Capital Cost
6. Waste Disposal	$0.03/liter coating ($0.11/gal)
II. Annualized Capital Charges	
1. Depreciation and Interest	0.1468 x Capital Cost
2. Taxes, insurance, administrative charges	0.04 x Capital Cost

[a]References 1 and 9, and EPA estimates.

lines are presented in Tables 3-3 and 3-4, respectively. Table 3-5 contains costs for powder coating, which applies to both lines combined. Again, remember that the direct operating cost for a process modification is an incremental cost; that is, it represents the increase or decrease when comparing the cost of the new coating system to the baseline solvent system.

For the prime coating line, Table 3-3 shows conversion to electrodeposition (EDP) coating to be more cost-effective than conversion to water-borne spray, despite its much higher installed cost. The EDP annualized credits range from $235,000 to $912,000/year for the 1,920 and 5,760 hours/year operations, respectively, compared to costs of $115,000 to $328,000/year for conversion to water-borne coating. Most of the cost discrepancy is attributable to the high incremental materials cost (excluding solvent) for water-borne coating, relative to solvent-borne prime: $114,000 to $341,000/year. The direct operating costs shown for water-borne coating also include credits for natural gas and waste disposal, and small costs for maintenance and electricity. To contrast, the EDP system has direct operating credits of $270,000 to $831,000/year, primarily due to incremental credits for materials and direct labor. Their solvent credits are about equal, at $58,000 to $174,000 and $53,000 to $158,000/year, respectively, for EDP and water-borne. Finally, the VOC control efficiencies for these options are 87 percent for EDP and 80 percent for water-borne.

However, Table 3-4 shows high-solids coating to be the most cost-effective control option for the model topcoat line. The total annualized

Table 3-3. CONTROL COSTS FOR MODEL EXISTING ELECTROSTATIC SPRAY PRIME COAT LINE (Baseline Production 768,000 units per year)[a]

	Water-borne Coating[b]			Electrodeposition (EDP) Coating[c]		
	1,920 hr/yr[d]	3,840 hr/yr	5,760 hr/yr	1,920 hr/yr	3,840 hr/yr	5,760 hr/yr
Installed capital cost ($000)[e]	40	40	40	500	500	500
Direct operating cost (credit) ($000/yr)[f]	160	320	478	(270)	(550)	(831)
Solvent credit ($000/yr)	(53)	(106)	(158)	(58)	(116)	(174)
Annualized capital charges ($000/yr)	8	8	8	93	93	93
Total annualized cost(credit):$000/yr:	115	222	328	(235)	(573)	(912)
$/unit	0.15	0.14	0.14	(0.31)	(0.37)	(0.40)
Solvent emissions controlled (Mg/yr)	157	314	471	171	342	513
Emission reduction (%)	80	80	80	87	87	87
Cost-effectiveness ($/Mg of solvent controlled)[g]	732	707	696	(1,370)	(1,680)	(1,780)

[a]References 1, 2, 5, 6, and 10.

[b]Costs are for extra insulation of equipment, and converting the spray booths to water wash.

[c]Costs are for new application equipment.

[d]1,920 hours/year corresponds to a production rate of 768,000 units/year; 3,840 hours/year corresponds to 1,536,000 units/y and 5,760 hours/year corresponds to 2,304,000 units/year.

[e]Capital costs have been rounded to the nearest ten thousand dollars; annualized costs, to the nearest thousand dollars.

[f]Includes all incremental costs except the solvent credit, which appears immediately below.

[g]The quotient of the total annualized cost ($/yr) and the solvent emissions controlled (Mg/yr.).

Table 3-4. CONTROL COSTS FOR MODEL EXISTING ELECTROSTATIC SPRAY TOPCOAT LINE
(Baseline Production: 768,000 units/yr.)[a]

	Process Modification								
	Water-borne Coating[b]			High-Solids Coating[c]			Powder Coating[d]		
	1920 hr/yr[f]	3840 hr/yr	5760 hr/yr	1920 hr/yr	3840 hr/yr	5760 hr/yr	1920 hr/yr	3840 hr/yr	5760 hr/yr
Installed capital cost ($000)[g]	30	30	30	40	40	40	750	750	750
Direct operating cost (credit)($000/yr)[h]	38	75	112	(45)	(98)	(152)	134	252	371
Solvent credit ($000/yr)	(32)	(64)	(96)	(31)	(62)	(93)	(38)	(76)	(114)
Annualized capital charges ($000/yr)	5	5	5	8	8	8	140	140	140
Total annualized cost(credit): $000/yr	11	16	21	(68)	(152)	(237)	236	317	397
$/unit	0.01	0.01	0.01	(0.09)	(0.10)	(0.10)	0.31	0.21	0.17
Solvent emissions controlled (Mg/yr)	95	190	286	91	181	272	113	226	339
Emission reduction (%)	80	80	80	76	76	76	95	95	95
Cost-effectiveness ($/Mg of solvent controlled)[j]	111	83	73	(758)	(845)	(872)	2,090	1,400	1,170

	Add-on Control System								
	Carbon Adsorber (spray booth)			Thermal Incinerator (oven)[e]			Total		
	1920 hr/yr	3840 hr/yr	5760 hr/yr	1920 hr/yr	3840 hr/yr	5760 hr/yr	1920 hr/yr	3840 hr/yr	5760 hr/yr
Installed capital cost ($000)[g]	500	500	500	79	79	79	579	579	579
Direct operating cost (credit) ($000/yr)[h]	44	61	77	10	17	24	54	78	101
Solvent credit ($000/yr)	0[i]	0	0	0	0	0	0	0	0
Annualized capital charges ($000/yr)	93	93	93	15	15	15	108	108	108
Total annualized cost (credit): $000/yr)	137	154	170	25	32	39	162	186	209
$/unit	0.18	0.10	0.07	0.03	0.02	0.02	0.21	0.12	0.09
Solvent emissions controlled (Mg/yr)	86	171	257	21	43	64	107	214	321
Emission reduction (%)	90	90	90	90	90	90	90	90	90
Cost-effectiveness ($/Mg of solvent controlled)[j]	1,600	901	665	1,170	750	611	1,510	869	651

[a]References 1 to 9.

[b]Costs are for extra insulation of equipment, and converting the spray booths to water wash.

[c]Costs are for converting solvent-borne spray coating line.

[d]Costs are for case where powder coating only replaces the solvent-based topcoat operation.

[e]Costs include primary heat recovery (35%)

[f]1,920 hours/year corresponds to a production rate of 768,000 units/year; 3,840 hours/year corresponds to 1,536,000 units/year; and 5,760 hrs/yr. corresponds to 2,304,000 units/year.

[g]Capital costs have been rounded to the nearest ten thousand dollars; annualized costs, to the nearest thousand dollars.

[h]Includes all incremental operating costs except the solvent credit, which appears immediately below.

[i]Credit is zero for add-on control systems, because there is no change in the solvent usage.

[j]The quotient of the total annualized cost ($/yr) and the solvent emissions controlled (Mg/yr).

credit for this system ranges from $68,000 to $237,000/year. Most of this credit is attributable to the incremental materials credit. This is so despite the fact that high solids coating is more expensive (at $3.18/liter) than the solvent-borne topcoating ($2.13/liter). However, when high-solids coating is used, the amount of coating required is sufficiently smaller to result in a much lower materials cost.

Conversion of the topcoat line to water-borne coatings is next in cost-effectiveness. As Table 3-4 shows, the direct operating costs are nearly offset by the solvent credits, which range from $32,000 to $96,000 per year. And because the incremental capital cost is relatively low ($30,000),so is the annualized capital charges. Consequently, the total annualized costs are relatively small, at $11,000 to $21,000 per year, respectively, for the 1,920 hours/year (one-shift) and 5,760 hours/year (three-shift) cases.

The add-on control systems--carbon adsorption on the spray booth and flash-off area, thermal incineration with primary heat recovery on the oven--have combined annualized costs of $162,000 to $209,000/year. Controlling a much larger volume, the adsorption system accounts for over 80 percent of these amounts. Most of this percentage is, in turn, attributable to the annualized capital charges for the adsorber.

Conversion of the topcoat line to powder coating is the least cost-effective of the options. The solvent credits shown in Table 3-4 do little to offset the annualized capital charges and direct operating costs. The former are due to the relatively high incremental investment ($750,000), while most of the latter are comprised of the incremental materials costs. These, in turn, range from $122,000 to $366,000 per year.

The systems in Table 3-4 also represent different levels of VOC emission reduction. The control efficiencies range from 80 percent for water-borne coating to 95 percent for conversion to powder coating. These efficiencies are reflected in the cost-effectiveness ratios, the quotients of the annualized costs and the VOC emissions controlled. (Cost-effectiveness is discussed in Section 3.2.2.)

Table 3-5 contains costs for replacing both prime and topcoat lines with powder coating. Unlike the powder coating option in Table 3-4, this option involves coating of both sides of the appliance, as opposed to only one side in the topcoat operation. For this reason, the investment ($1,180,000) is much higher. Despite this high investment, the annualized capital charges are more than offset by the solvent credits and direct operating credits with the 3,840 and 5,760 hours/year cases. Finally, powder coating represents the highest control efficiency for the model plant: 95.0 percent.

3.2.2 Cost-Effectiveness

As Tables 3-3 through 3-5 show, the cost-effectiveness ratios for the several control alternatives cover a broad range. This reflects not only the range in annualized costs, but the various control efficiencies and the uncontrolled emission rates for the solvent-borne prime and topcoat lines.

The annualized costs and emission reductions for the individual coating lines have been used to calculate the cost-effectiveness ratios and VOC emission control efficiencies for the model plant.

Table 3-6 lists these parameters, along with nine combinations of prime and top coating line control alternatives. Listed in decreasing order, the overall control efficiency goes from 95.0 percent (powder coating) to

Table 3-5. COSTS FOR CONVERTING MODEL EXISTING ELECTROSTATIC SPRAY COATING LINES TO POWDER COATING (Baseline Production: 768,000 units/yr)[a]

Item	Value[b]		
	1920 hr/yr[c]	3840 hr/yr	3760 hr/yr
Installed capital cost ($000)[d]	1,180	1,180	1,180
Direct operating cost (credit) ($000/yr)[e]	(44)	(112)	(180)
Solvent credit ($000/yr)	(104)	(208)	(312)
Annualized capital charges ($000/yr)	220	220	220
Total annualized cost (credit): $000/yr.	72	(100)	(272)
$/unit	0.09	(0.07)	(0.12)
Solvent emissions controlled (Mg/yr)[f]	309	618	927
Emission reduction (%)	95	95	95
Cost-effectiveness ($/Mg of solvent controlled)[g]	233	(162)	(293)

[a]References 1 to 3.

[b]Since no prime coat is needed with powder coating, these are incremental costs for converting both coating lines

[c]1,920 hours/year corresponds to a production rate of 768,000 units/year; 3,840 hours/year corresponds to 1,536,000 units/year; and 5,760 hours/year corresponds to 2,304,000 units/year.

[d]Capital costs have been rounded to the nearest ten thousand dollars; annualized costs, to the nearest thousand dollars.

[e]Includes all operating costs except the solvent credit, which appears below.

[f]These are the total emissions controlled from both prime and topcoat lines.

[g]The quotient of the total annualized cost ($/yr) and the solvent emissions controlled (Mg/yr).

Table 3-6. COST-EFFECTIVENESS SUMMARY FOR MODEL PLANT CONTROL ALTERNATIVES[a]

Control Alternatives		Cost-Effectiveness ($/Mg)[b]			Control Efficiency (%)[b]
Prime Coat Line	Top Coat Line	1920 hr/yr[c]	3840 hr/yr	5760 hr/yr	
1. Powder coating[d]	Powder coating[d]	233	(162)	(293)	95.0
2. EDP coating	Powder coating	4	(451)	(604)	90.3
3. EDP coating	Carbon adsorption and thermal incineration	(263)	(696)	(843)	88.4
4. Water-borne coating	Powder coating	1,300	998	895	85.7
5. EDP coating	Water-borne coating	(842)	(1,050)	(1,120)	84.6
6. Water-borne coating	Carbon adsorption and thermal incineration	1,050	773	678	83.8
7. EDP coating	High-solids coating	(1,160)	(1,390)	(1,460)	83.2
8. Water-borne	Water-borne coating	500	472	461	80.0
9. Water-borne coating	High-solids coating	190	141	122	78.6

[a]References 1 through 10.

[b]The cost-effectiveness and control efficiency numbers are for the prime and topcoat control alternatives combined.

[c]1,920 hours/year corresponds to a production rate of 768,000 units/year; 3,840 hours/year corresponds to 1,536,000 units/year; and 5,760 hours/year corresponds to 2,304,000 units/year.

[d]With this option, powder coating replaces both the prime and topcoat operations.

78.6 percent for the combination of spray water-borne prime coating and high-solids top coating. However, between these efficiency extremes, the cost-effectiveness varies unevenly, from ($1,460) to $1,300/Mg of solvent removed.

For discussion purposes, the control combinations can be grouped into two efficiency ranges: moderate (78.6 to 90.3 percent) and high (95.0 percent). If a high control efficiency were required, the prime and top coat lines would be converted to powder coating. Its cost-effectiveness ranges from ($293) to $233/Mg.

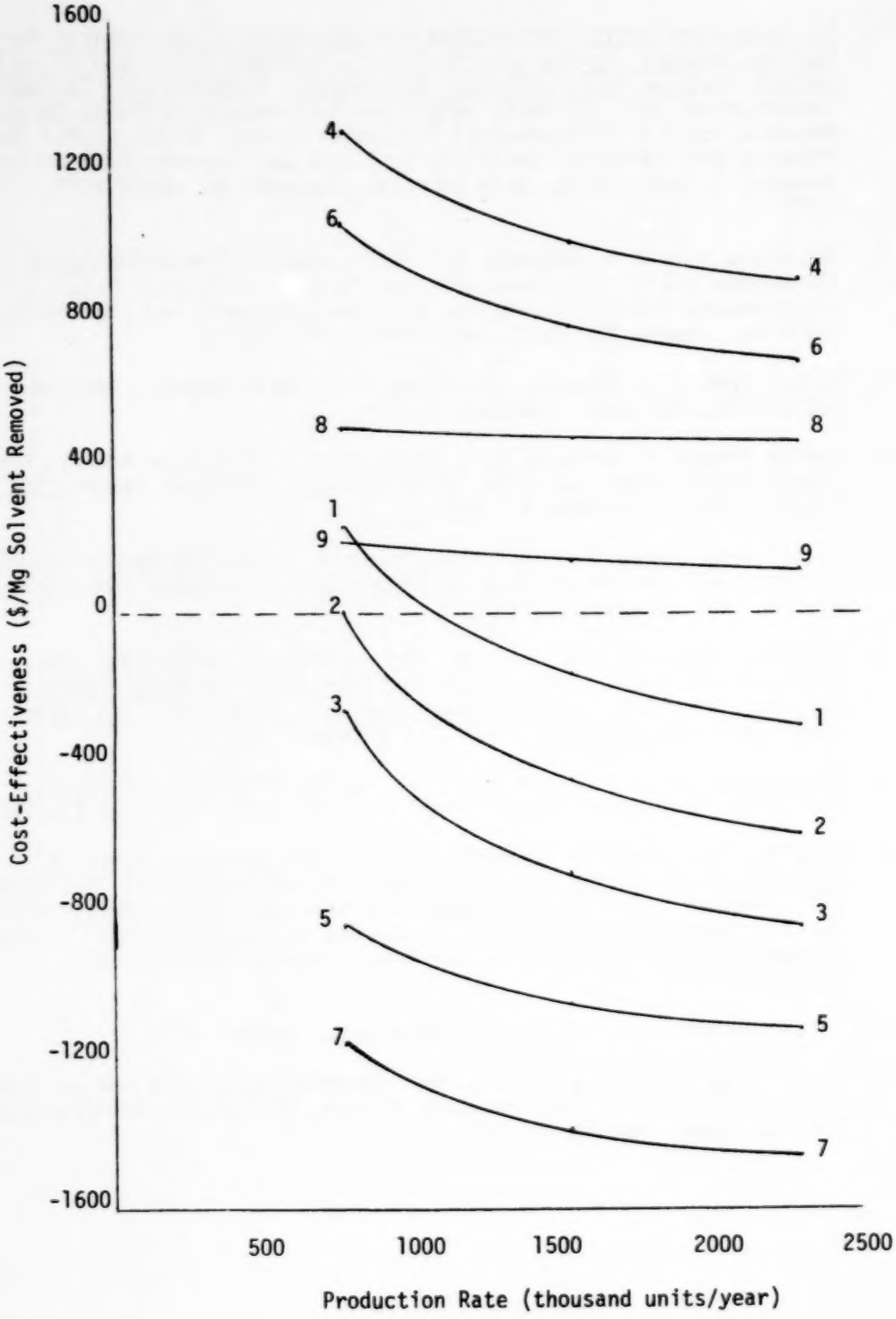
On the other hand, the combination of EDP prime coating and high-solids ($1,160)/Mg, top coating would be the most cost-effective selection at ($1,460) to ($1,160)/Mg, if a moderate emission reduction were necessary. At 83.2 percent, the control efficiency for this combination falls about midway in the moderate efficiency range.

EDP prime coating, in successive combination with water-borne conversion of the topcoat line and carbon adsorption-thermal incineration yield the next lowest cost-effectiveness ratios, at ($1,120) to ($842)/Mg and ($843) to ($263)/Mg, respectively. Compared to the other six combinations in the moderate efficiency range, these are low values. These low ratios, in turn, are mainly attributable to the relatively low incremental annualized cost of EDP prime coating, when compared to spray water-borne coating (See Table 3-3.)

Finally, the cost-effectiveness ratios have been plotted against the three production rates. Figure 3-1 displays these nine cost-effectiveness curves, each numbered according to its corresponding control option in Table 3-6. Note how the cost-effectiveness decreases with increasing

production rate. For most of the curves this decrease is pronounced. However, for curves 8 and 9, the cost-effectiveness decreases only slightly with increasing production rate. The control options corresponding to these curves involve small capital expenditures. Hence, their annualized costs are heavily weighted toward those costs and credits proportional to the production rate, such as materials, labor, and solvent. Of course, the amount of solvent emissions removed is also proportional to the production rate. Thus, for options 8 and 9, the cost-effectiveness ratio--the quotient of annualized cost and solvent removed--is virtually insensitive to changes in the production rate.

Figure 3-1. Cost-Effectiveness Curves for Model Plant Control Alternatives



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4.0 ADVERSE AND BENEFICIAL EFFECTS OF APPLYING TECHNOLOGY

This chapter provides the adverse and beneficial effects of each technique which reduces VOC emissions. These effects are not necessarily environmental but also include energy, cost, and any limitations of low organic solvent technology as compared to conventional high organic solvent coatings.

4.1 ELECTRODEPOSITION

Several other advantages, in addition to reduced VOC emissions, acrue from converting to electrodeposition.

· The major one is good quality control as a consequence of the fully automated process.

· It provides excellent coating coverage, corrosion protection, and detergent resistance because the paint particles are able to get into small recesses of parts.[1] However, because the coverage is so uniform, electrodeposition does not "mask" metal imperfections.

· Fire hazards and potential toxicity are decreased in electrodeposition due to the reduction of organic solvent content.

· If electrodeposition replaces a spray coating operation, solids and liquid wastes associated with spraying operations will be reduced drastically.

· The lower organic content permits lower ventilation rates, resulting in reduced energy consumption.

There are several disadvantages to the electrodeposition process.

· Conversion to coating large appliance parts by electrodeposition may increase electrical consumption. The amount will depend on the original application system, the size of the electrodeposition bath, and the thickness of the coating applied. In electrodeposition, electrical energy is required for the coating system, the refrigeration to overcome the temperature rise from the electrical process, for good paint circulation in the bath and operate the ultrafilter. Electrodeposition may consume three times as much energy as the water-borne flow or dip coating operations.[2] This would not be true if electrodeposition replaces a spraying operation. For example, energy credit must be given for elimination of high volumes of treated air necessary for spray booths. Energy consumption will also be less in the baking process. The air flow in the oven may be reduced and the flashoff tunnel may be omitted.

· If the hooks which hold the appliance parts are not properly hung or cleansed, the electrical contact may be faulty and the coating will not adhere to the metal.

· Conversion to electrodeposition will also necessitate a change of equipment at significant capital cost. The use of electrodeposition can be expensive on small scale production lines.

4.2 WATER-BORNE - SPRAY, DIP,OR FLOWCOAT

There are several advantages to converting to water-borne coatings.

· Conversion to water-borne coatings will likely be the first option considered by many facilities because of the possibility that these coatings can be applied essentially with existing equipment.

· Converting to water-borne coatings provides a potential decrease in toxicity and flammability.

· Water-borne coatings may be thinned with water, and coating equipment can be cleaned or flushed with water rather than organic solvent. When they are dry, however, water-borne coatings must be cleaned off application equipment with solvent, since they are then no longer soluble in water.

· Curing water-borne coatings may allow a decrease in oven temperature and some reduction in air flow since the amount of organics evaporating in the oven is reduced.[3] Air flow reduction, however, may be limited by high humidity occurring within the oven from water-borne coatings, potentially causing improper curing of the film and condensation on the oven walls.

There are several disadvantages to water-borne coatings when compared with conventional organic-borne coatings.

· The coating of large appliance parts with sprayed water-borne coatings may require closer attention than with organic-borne coatings because temperature, humidity, gun-to-metal-part distance, and flashoff time may change the appearance and performance of the coatings.

· Some spray equipment may have to be replaced or protected from corrosion.

· On many large electrostatic lines, spraying water-borne may be impractical because of the difficulties involved in isolating the entire system successfully. (Many water-borne coatings, however, may be easily sprayed electrostatically, with conventional air,or with airless spray methods).

· Water-borne coatings applied by conventional dip and flow coating application equipment will need to be monitored more closely due to their sensitive chemistry.

· Cleansing and pretreatment are more critical because of possible coating contamination and pH changes within the dip or flowcoating tank.[4] Although an additional rinse may be needed, they dry-off oven can be eliminated in some cases prior to coating.[5]

· As in spraying, some equipment may have to be replaced or adjusted (due to different surface tension of water than that of organic solvent) or protected from corrosion.[6] In one converted flowcoating operation, only the number of spray nozzles for the flowcoater had to be doubled to obtain the same coverage as with conventional coatings.[7]

· The coating bath, flashoff time, temperature, air circulation, and humidity may have to be altered and frequently monitored, because changes in weather conditions may affect the application of water-borne coatings.[8]

· Sludge handling may be more difficult because the water-borne coating does not settle as well.

4.3 POWDER

There are several advantages obtained after a facility is converted to apply powder coatings besides the substantial reduction in emissions.

· There are no solid or liquid wastes to be disposed of as compared to solvent-borne coatings,

· Powder does not require the purchase of additional solvents to control the viscosity of the coating or to clean the equipment.

· Powders can mask imperfections or weld marks in the metal.

· Conversion to powder coatings may reduce energy requirements in a spray booth because the large volumes of fresh air required for application of solvent-borne coatings are no longer required.

· If the powder recovery unit is highly efficient in collecting overspray, the cleaned air may be returned to the working area.

· Energy usage may also be reduced due to the elimination of the flashoff tunnel and decreased air requirements for the ovens, It has been estiamted that a 35-50 percent overall reduction in energy requirements will result in replacing a single coat applciation with powder, and 55-70 percent reduction will occur when a two-coat applications is replaced with powder.[9]

· Powder can be reclaimed resulting in up to 98 percent coating efficiency. However, not all reclaimed powders are suitable for reuse. Powder containting a buildup of powder fines will have to be discarded, and the larger and heavier granules will have to be reprocessed again before they are suitable for reuse.[10]

There are disadvantages encountered when applying powders.

· All application equipment, spray booths and associated equipment (and often ovens) used for liquid systems must be replaced. This will then limit the flexibility to apply other coatings on appliances because only powders can be applied with this type of equipment.

· Coating film thicknesses of less than 2 mils have not been successfully obtained with powders on a production line basis.

· Metallic powders have not yet been successfully developed.

· Color matching during manufacturing of powder is difficult.

· Powder films have appearance limitations.

· Recesses are often difficult to cover effectively due to Faraday caging effect without resulting in application of thicker films of coating.

· Excessive humidity during storage and application can affect the performance of powders

· Powder coatings are also subject to explosions as are many particulate dust due to difficulties in obtaining enough ventilation at all times.[11]

· Color changes for powder require about half an hour down time if powder is recovered for reuse. This would greatly curtail production capacities in large appliance facilities. Color changes may be shortened if powders are not reclaimed in their respective colors, but results in a coating usage efficiency of only 50 to 60 percent.

· Powders may present application difficulties at the high line speeds which many of the large appliance manufacturers operate.

4.4 HIGHER SOLIDS COATINGS

One of the greatest advantages of converting to higher solids coatings is that they may be applied with existing equipment, although some application equipment (i.e., spray guns) may have to be replaced or a paint heater may have to be installed to reduce the viscosity of the higher solids coatings. Conversion to high-solids coatings can permit reduced energy consumption. Air flow in the spray booth can be decreased because less organic solvent is applied for each dry mil thickness of film. The energy consumption by the oven and the flashoff tunnel may also be reduced by reducing the volume of the oven exhaust otherwise necessary to maintain a low concentration[12] of organic solvents. Solid and liquid waste may also decrease since less coating is applied per dry mil. However, the tackiness of high solid coatings may make cleanup more difficult.[13]

Although the organic solvent content is reduced, this reducing the level of toxicity, there is a potential health hazard associated with isocyanates used in some high-solid two-component systems.

4.5 CARBON ADSORPTION

Although the technology is well documented and considered technically feasible, there are no large appliance or other metal coating facilities known to be using carbon adsorption on application and flashoff areas. The additional energy required to operate a carbon adosrption system is a potential disadvantage. The energy requirement will depend on the type of application, the size of adsorber(s) and the concentration of the solvents entering the carbon bed. Any reduction which can be made in the amount of air flow from the coating application and flashoff areas will result in less energy usage because a smaller adsorber can be installed.

The amount of solid and liquid waste generated by the use of a carbon adsorber will depend on the coating application system. Organics emitted by the flow and dip coating operations will not require filtration or scrubbing of the inlet gas stream into an adsorber. However, emissions from spray booths may require additional filtration or scrubbing since overspray may not be completely removed by the spray booth collectors. Some solvents are water miscible and may produce a water pollution problem if regeneration steam is condensed and discharged untreated. This, nowever, can be solved by incinerating the uncondensed steam and solvent together, or by stripping the condensate and disposing of the solvents. Either will increase the cost and energy consumption of the carbon adsorption unit. There is little possibility that the recovered solvents may be reused in the large appliance industry because of the variety of solvent mixtures used.

An important factor to consider for carbon adsorption is plant space. Many large appliance facilities may require many dual-bed carbon adsorption units in parallel operation. These will require a relatively large plant area.

4.6 INCINERATION

The most common and widely applicable technique used for the reduction of organic emissions is incineration. One disadvantage is the quantity of additional fuel required unless heat recovery is used. The use of primary (preheat of the inlet gas stream to near incineration temperature) and secondary (use of heat from the incinerator exhaust for other energy-using processes) heat recovery will reduce energy consumption and perhaps even reduce the plant's overall consumption if there are enough areas where secondary heat may be utilized. Table 4-1 shows the potential decreases in energy usage when using tube and shell heat exchangers with incineration. Some examples (besides preheating the incinerator inlet) where heat from the incinerator exhaust may be used are: oven makeup air, boiler, cleansing processes, dryoff ovens, and plant heat. Greater heat recovery efficiencies (85-90 percent) than those shown in Table 4-1 may be obtained with other forms of heat exchangers (ceramic wheel and stone packed beds) which can be very attractive for low organic concentration streams.

TABLE 4-1

BURNER REQUIREMENTS FOR INCINERATORS
IN 10^6 BTU/HR[a,b,14]

NON-CATALYTIC INCINERATORS	5 percent LEL	15 percent LEL
No Heat Recovery		
5000 scfm	5.82	4.05
15,000 scfm	17.48	12.16
30,000 scfm	34.95	24.31
38% Efficient Primary Heat Recovery		
5000 scfm	3.32	1.56
15,000 scfm	10.09	4.73
30,000 scfm	19.97	9.38
Primary and 55% Efficient Secondary Heat Recovery		
5000 scfm	1.42	-0.34
15,000 scfm	4.40	-0.66
30,000 scfm	8.67	-1.82
CATALYTIC INCINERATORS		
No Heat Recovery		
5000 scfm	1.69	1.69
15,000 scfm	5.07	5.07
30,000 scfm	10.14	10.14
38% Efficient Primary Heat Recovery		
5000 scfm	0.79	0.26
15,000 scfm	2.38	0.77
30,000 scfm	4.76	1.54
Primary and 55% Efficient Secondary Heat Recovery		
5000 scfm	-0.21	-1.07
15,000 scfm	-0.62	-3.22
30,000 scfm	-1.24	-6.46

a) Based on 300°F oven outlet temperature; 1400°F outlet temperature for non-catalytic and 600°F inlet temperature for catalytic incinerators.

b) (-) indicates net overall fuel savings.

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5.0 MONITORING TECHNIQUES AND ENFORCEMENT ASPECTS

This chapter discusses the recommended emission limit, the monitoring techniques and enforcement aspects of coatings low in organic solvents and add-on control equipment for reducing VOC emissions.

As stated in the Preface, there is no universal VOC emission control technique applicable for all large appliance coating operations because of the large variety of appliances manufactured and the variety of coating application methods used. The recommended emission limit (2.8 lbs of organic solvent per gallon of coating)for the large appliance industry is based on electrodeposition or water-borne coatings for primer and interior single coat, and on water-borne or higher-solids coatings for topcoat and exterior single coat applications. For large appliance coating facilities, it is recommended that emission limitations be expressed in terms of organic solvent content of the coating since these values can be determined with relatively simple analytical techniques. To permit operators to use add-on control equipment, alternative compliance procedures should be allowed. Sample calculations to verify compliance with this emission limit are shown in Appendix A.

Limitations in VOC may be expressed in terms of mass or volume and may be based on the entire coating (including organic solvent) or only on paint solids. In this guideline, limitations are expressed as the allowable mass of organic solvent per unit volume of coating (kgs per liter of coating or lbs per gallon of coating) as it is delivered to the coating applicator. The water content of the coating is not included in the ratio. The principal advantage of this format is that enforcement is relatively simple. Field

personnel can draw samples and have them analyzed quickly. A disadvantage is that the relationship between the solvent fraction and organic emissions is not linear. If the organic solvent content is expressed in terms of mass of organic solvent per unit volume of paint solids (kgs per liter or lbs per gallon of solids), the disparity disappears. This relationship is linear and more readily understood e.g., a coating containing 2 lbs of organic solvent per gallon of solids releases twice as much organic solvent as one with one pound per gallon. The disadvantage of this format, however, is that the analytical methods are more complex. Appendix A of Volume II "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks", presents ASTM test methods for determination of the pounds of organic solvents per gallon of coating (minus water).

Other options such as weight or volume of organic solvent per kilogram of coating are generally less desirable although they may be entirely appropriate for a given industry. Basing limitations on the mass of coating or paint solids is not recommended because the specific gravity of coatings tends to vary widely with the degree and type of pigment employed. Highly pigmented paints have much greater density than unpigmented clear coats or varnishes.

The recommended limitation assumed the large appliance facility merely converts from use of an organic-borne coating to a coating low in organic solvent. It does not consider any reduction in VOC emissions which may result from a decrease in film thickness or an increase in the transfer efficiency of a coating. For example, assume a facility applying conventional coating at 1.2 mils film thickness, converts to a coating which, although it contains

less organic solvent, it is not quite low enough to meet the recommended emission limit. However, if the new coating has better hiding power and is servicable with only 0.8 mils film thickness, it may still result in a reduction in VOC emissions comparable to a coating which meets the recommended emission limit. Another example would be a facility that converts from a manual conventional spray application (at a transfer efficiency of 40-70 percent), to an automated electrostatic spray system (at a transfer efficiency of 70-90 percent), or from any spray system to a flow or dip coat system (at a transfer efficiency of at least 90 percent). In each case, a reduction in VOC emissions will be realized. This reduction in VOC content can be considered in any evaluation of the overall reduction achieved by the operator.

In those few facilities where add-on control equipment is a more likely option, it may be more appropriate to state emission limits in terms of control efficiency across the incinerator, adsorber, etc. Where limitations are expressed only in terms of the solvent content of the coating, it will be necessary to determine the mass emission rate from the control system and relate it to the quantity of coating applied during the test period. This is a more complicated procedure since it may not be easy to determine the amount of coating consumed during the test period and an analysis by mass of the organic solvent directed to the control device would be even more difficult. Chapter 5 of "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume I: Control Methods for Surface Coating Operations" presents approaches which may be used. When add-on type devices are selected as the compliance method the air pollution control agency should require that the coating lines be equipped with an approved capture device to assure effective control. The capture system will likely have to be

custom designed to accommodate the plant-to-plant variables which affect performance. When reviewing the design of such a system, however, the air pollution control offical must consider requirements imposed by the Occupational Safety and Health Administration and the National Fire Prevention Association.

Some coatings will emit a greater amount of VOC than merely its solvent content. This incremental VOC may come from three possible sources. The first is the possibility that some of the monomer may evaporate. Also, if it reacts by condensation polymerization, the evolution of by-product compounds may be a compounding factor. Finally, it has been reported that the industry is using increasing quantities of "blocking agents" which are released from the polymer matrix during the curing process.

There are now no approved analytical methods certified by the agency for determining the quantity of VOC emitted by such reactions, although certainly the organic mass emission rate could be determined by expensive and sophisticated analytical techniques. The more practical means of quantifying the contribution of the polymerization reaction to the overall emission problem would be by contacting the manufacturer of the coating. Certainly, his knowledge of the fundamental chemical mechanisms involved would allow calculation of an emission rate based on the chemical reaction.

This emission will occur during the cure (if at all) which is usually temperature initiated by the oven. If the oven is controlled by an incinerator, then verification of the efficiency of the device should be sufficient to assure compliance with the coating regulations.

APPENDIX A

SAMPLE CALCULATIONS OF CONTROL OPTIONS

This appendix aids the local agency in determining if a coating proposed for use by a large appliance facility will meet the recommended emission limit of 0.34 kilograms of VOC per liter of coating applied, (2.8 lbs/gal) excluding any water that the coating may contain. The purpose of excluding water is to preclude compliance through dilution with water. This appendix also explains how to compare the actual VOC emissions from a facility regardless of the type of low-polluting coating or add-on control device used.

The purpose of all coating operations is to cover a substrate with a film that provides both corrosion resistance to the substrate and esthetic appeal. Therefore, the rational basis for specifying an allowable VOC emission limit would be in units of coating volume (e.g., grams of VOC per square meter (lbs/sq.ft) per unit thickness of film). However, the complexity of any analytical method which would provide a measurement of the volume of a cured coating precluded this approach. As a compromise, the limitations were developed in kilograms (lbs) of VOC per unit volume of uncured solids and organic solvent. Mathematically, then, the emission factor (ef) for a coating would be expressed as:

(1) $ef = \frac{(\text{volume fraction organic solvent})(\text{average organic solvent density})}{\text{volume fraction of solids} + \text{volume fraction of organic solvent}}$

or (2) $ef = \frac{(\text{volume fraction organic solvent})(\text{average organic solvent density})}{1 - \text{volume fraction of water}}$

The following examples show the use of these equations to determine the emission factor for both organic solvent-borne and water-borne coatings.

CASE 1: Determine the emission factor for an organic solvent-borne coating which contains 35 volume percent organic solvent.

Therefore: $ef = \frac{(.35)\ (0.88\ \text{kg/liter}^*)}{1 - 0}$

= 0.31 kgs/liter (2.6 lbs/gal)

Since the emission factor is less than the recommended limit of 0.34 kg/liter (2.8 lbs/gal), this coating is in compliance.

CASE 2: Determine the emission factor for a water-borne coating containing 75 volume percent organic solvent. Of that 75 percent solvent, 80 volume percent is water and 20 percent is organic solvent.

Since 80 percent of the solvent is water, the respective volumes of water and organic solvent may be calculated as shown:

Volume water = .80 x .75 liter = .6 liter

Volume organic solvent = 0.75 liter - .6 liter = .15 liter

Therefore: $ef = \frac{(0.15)\ (0.88\ \text{kg/liter})^*}{1 - 0.6}$

= 0.32 kg/liter (2.64 lbs/gal)

This coating also has an emission factor less than the recommended limit and would comply.

*This density is considered typical and is equal to 7.36 lbs/gal.

The level of control represented by 0.34 kg/liter of coating (2.8 lbs/gal) less water can also be achieved with a conventional high organic solvent coating if suitable add-on control equipment is installed. However, this method of determining the equivalent emission limit factor is not as straightforward as the previous two cases and must also consider the volume of solids in the coating.

CASE 3: Determine the emission factor for a conventional organic-borne coating containing 75 volume percent organic solvent.

$$\text{Therefore: } ef = \frac{(.75)\ (.88\ \text{kg/liter})^*}{1 - 0}$$

$$= 0.66\ \text{kg/liter (5.5 lbs/gal)}$$

However, this liter of coating contains only 0.25 liter of solids whereas the coating which represents the recommended emission limit of 0.34 kg.liter (2.8 gal) contains 0.61 liter of solids.
(This can be back calculated from the recommended emission limit in this manner.)

$$\text{i.e. } 0.34 = \frac{(x)\ (0.88\ \text{kg/liter})}{1 - 0}$$

$$x = 0.38, \text{ volume percent organic solvent}$$

$$\text{Therefore fraction of solids} = 1 - x = 0.62$$

On a unit volume of solids basis, the conventional coating contains:

$$\frac{0.66\ \text{kg organic solvent}}{0.25\ \text{liter solids}} = \frac{2.64\ \text{organic solvent}}{\text{liter solids}} \left(\frac{22\ \text{lbs VOC}}{\text{gal solids}}\right)$$

And the recommended limit reference coating contains

$$\frac{0.34\ \text{kg organic solvent}}{0.62\ \text{liter solids}} = \frac{0.55\ \text{kg organic solvent}}{\text{liter solids}} \left(\frac{4.61\ \text{lbs VOC}}{\text{gal solids}}\right)$$

Consequently, in order for the conventional coating to emit no more VOC than the reference coating, the add-on control device must capture and destroy (or collect) 2.09 kg of solvent per liter of solids applied (2.64 - 0.55). This will require a control system that is at least 79 percent efficient. Since the add-on control devices can often operate at 90 percent efficiency or greater, the agency must insure that at least 86 percent of the VOC emitted by the coating is captured and delivered to the add-on control device. Since it will normally not be practical to attempt the complex analytical program essential to develop a material balance around the coating application and flashoff areas and ovens, the agency will normally certify an acceptable capture system based on good engineering practice.[1]

APPENDIX A REFERENCE

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